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Effects of Harvesting on Population Structure of Leatherleaf Fern (*Rumohra adiantiformis* (G. Forst.) Ching) in Brazilian Atlantic Rainforest

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Abstract.—Among ferns, the leatherleaf fern (*Rumohra adiantiformis*) is of particular economic importance. The fronds are sold around the world for flower arrangements. In Brazil, these fern fronds represent an income source for numerous households, working with a traditional management system with a maximum of three annual collections in the same area. The purpose of this study was to evaluate the demographic structure of managed *R. adiantiformis* populations in the south of Brazil and verify the sustainability of the harvesting activity in this region. The study was conducted in an area of Atlantic Rainforest in the State of Rio Grande do Sul. The demographic structure of the managed populations was evaluated in permanent plots, where fronds in the different development phases were counted quarterly for one year. Rainfall was identified as the main factor influencing bud emergence and development. A reduction in *R. adiantiformis* populations related to forest regeneration was also observed. Fast frond regeneration and the absence of differences between managed and non-managed populations concerning the proportions of buds and young fronds corroborate the ecological sustainability of the management system used by the local harvesters. The results obtained differ largely from those of populations studied in South Africa, where *R. adiantiformis* plants seem unable to maintain frond density and size when harvested. These contrasting results are probably related to climatic differences between these areas, especially annual rainfall, which is higher in Brazil allowing for the rapid regeneration and sustainable management of this resource in the Brazilian Atlantic Rainforest.

Key Words.—sustainable management, tropical forests, demography, non-timber forest products

Non-timber forest products (NTFPs) are biological non-wood resources/ products, which can be obtained from natural and managed forests for consumption and/or trade (Peters, 1994). NTFPs are a source of social and economic benefits, particularly for local or traditional communities. More adequate management regimes for the exploitation of a great number of NTFPs should, however, be determined (Shanley *et al.*, 2002). Information about the autoecology and management effects on populations is available only for a limited number of species.

Despite the economic importance of several fern species around the world, there is still surprisingly little information on the impacts of frond harvesting on fern populations (Ticktin *et al.*, 2007). One of the most important NTFPs in Brazil is the pteridophyte *Rumohra adiantiformis* (G. Forst.) Ching (leatherleaf fern). This species is of particular economic importance among ferns and its

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TABLE 1. Geographical placement and status of leatherleaf fern (*Rumohra adiantiformis* (G. Forst.) Ching) study populations.

Population	Geographic coordinates	Altitude (m)	Status	Harvest period
1	29°55′S/50°23′W	253.91	Managed	Sep 2004
2	29°64′S/50°14′W	355.09	Managed	Aug 2004; Aug 2005
		225.07		Nov 2004; Mar 2005;
3	29°60′S/50°15′W		Managed	Jun 2005
4	29°56′S/50°23′W	245.02	Non-managed	Zero

fronds are sold all over the world for floral arrangements. Leatherleaf fern fronds are particularly popular thanks to their long post-harvest life.

In Brazil, the fronds are extracted mainly from the natural environment and harvested in Atlantic Rain Forest areas in the south and southeast of the country (Conte *et al.*, 2000; Coelho de Souza, 2003). More than 50% of the *R. adiantiformis* traded in Brazil comes from Rio Grande do Sul (Anama, 2002) and the major source of income of about 2000 rural households in the northeastern region of Rio Grande do Sul is based on harvesting and trading *R. adiantiformis* fronds (Coelho de Souza *et al.*, 2006).

Although the plants are not collected (only the fronds), frond harvesting may cause impacts on *R. adiantiformis* populations by reducing rhizome growth, frond density and size, and effective population size (Milton and Moll, 1988; Geldenhuys and Van der Merwe, 1988; Baldauf *et al.*, 2008). Detailed knowledge about the impacts of the management system used by local harvesters is therefore required to determine conditions of sustainable extraction of this resource. The purpose of this study was to evaluate the demographic structure of managed populations of *R. adiantiformis* in the south of Brazil, as well as to verify the sustainability of the harvesting activity in this region.

MATERIAL AND METHODS

Study area and sampled populations.—Four populations were studied in Maquiné, a municipality in the northern coastal region of the State of Rio Grande do Sul, Brazil (Table 1). This area is considered the southern limit of the distribution of Atlantic Rainforest in Brazil. Populations one, two, and three were managed according to traditional knowledge, in which harvesting occurs in any month of the year, with a maximum of three annual collections permitted in the same area. In general, all fronds longer than 30 cm are harvested.

Population four was evaluated in an area of species occurrence where fronds are not harvested; this population served as a reference of the population demographic structure without exploitation, which is rare in the study area. This population is located in a private area with the same ecological

TABLE 2. Correlation coefficient of the demographic and phytossociological descriptors for the first three ordination axes of the principal component analysis (PCA). The values in bold were used for interpretation of the axis. The first three axes explained 76.8% of the total data variation.

Descriptors	Axis 1	Axis 2	Axis 3
No. of buds (BUD)	0.66	−0.07	0.13
No. of young fronds (YOU)	**0.74**	0.39	0.28
No. of adult fronds (ADU)	**0.82**	0.15	0.32
No. of dead fronds (DEA)	0.67	−0.17	−0.49
Total no. of fronds (TOT)	**0.97**	0.12	0.10
No. of fertile fronds (FER)	0.47	−0.53	−0.55
Basal area (BA)	**−0.78**	0.22	−0.01
Diameter at Breast Height (DBH)	−0.28	**0.82**	−0.29
No. of trees (TRE)	−0.40	**−0.70**	0.43

conditions as the others, but its owner decided to allow forest regeneration to take place and maintain the area for biological conservation. It was impossible to conduct a replication of the unharvested area due to the lack of populations large enough for experimental studies and free from exploitation.

Evaluation of demographic structure.—Demographic structure was characterized using four 5 × 5 m plots in each of the four study populations. Since *R. adiantiformis* is a rhizomatous plant, the fronds were considered individual units. The fronds were counted at each development stage, in four categories: buds, young fronds, adult fronds, and dead fronds. The presence of fertile fronds was verified as well. The fronds were counted quarterly for one year, with evaluations in August 2004, November 2004, February 2005, May 2005 and August 2005. In those cases in which harvesting and monitoring occurred in the same month, the evaluations were carried out before frond harvesting.

The respective environments of the sampled units were characterized based on data of the existing tree and shrub plants in the plots. The parameters evaluated were: number of plants (height of over 1.30m, independent of the species) and diameter at breast height (DBH – 1.30m), the latter measured with a pachymeter. This evaluation was carried out in an area of 8 × 8 m in the center of the plots described above and all non-fern species were measured.

Data analysis.—Correlation analysis and principal component analysis (PCA) were used for the demographic data analysis and possible relations with phytossociological descriptors. The demographic descriptors were: BUD (number of buds), YOU (number of young fronds), ADU (number of adult fronds), DEA (number of dead fronds), TOT (number of total fronds) and FER (number of fertile fronds). The phytossociological descriptors were: BA (basal area), DBH (diameter at breast height) and TRE (number of trees). The descriptors that contributed the most to axis formation, with correlations equal to or higher than 0.70, were used in the interpretation. The population structure was compared using the Kolmogorov-Smirnov test with Bonferroni correction for multiple comparisons. Statistical analyses were performed using Statistica 6.0 (StatSoft, 1998) and MVSP (Multivariate Statistical Package) version 3.12 d (Kovach, 2001).

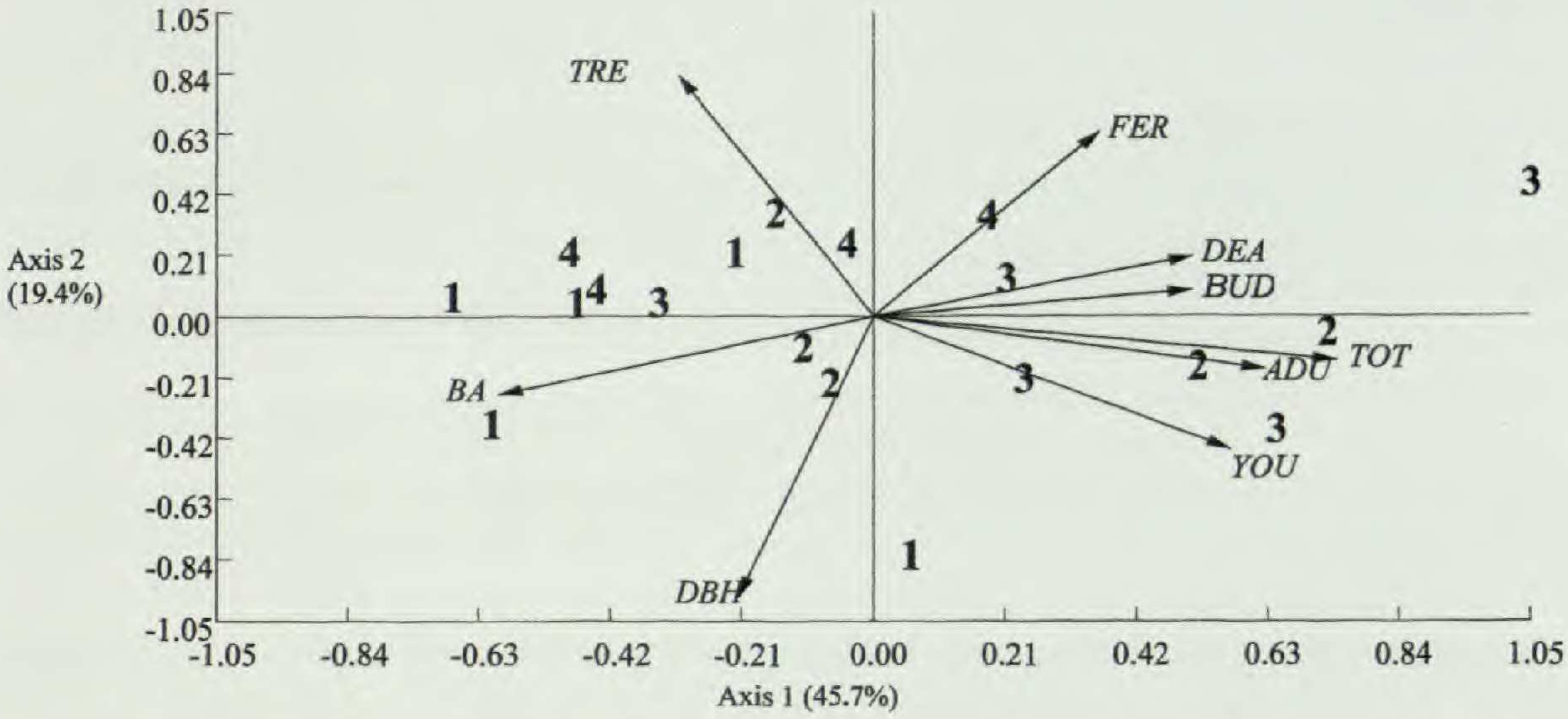

FIG. 1. Principal component analyses of phytossociological and demographic data of four *Rumohra adiantiformis* populations. The numbers represent the sample units (plots) of each population and the descriptors are: BUD (number of buds), YOU (number of young fronds), ADU (number of adult fronds), DEA (number of dead fronds), TOT (number of total fronds), FER (number of fertile fronds), BA (basal area), DBH (diameter at breast height), and TRE (number of trees).

RESULTS

Environmental aspects.—Large variations in the number of fertile fronds, as well as in the number of fronds in each development category, were observed in the populations studied. The number of fertile fronds was the most variable. The coefficients of variation obtained for each category were: buds (75.1%), young fronds, (51.9%) adult fronds, (47.7%), dead fronds (39.3%) and fertile fronds (144.8%). The existence of seasonality was verified in the formation of new fronds (buds). Bud emergence was more intensive at the end of winter and the beginning of spring (between August and September). A correlation between some climatic factors and frond production in the species was also observed. The correlation between the number of buds and mean monthly rainfall was negative ($r^2 = -0.58$; $p < 0.01$) and positive between the number of buds and rainfall in the three months before evaluation ($r^2 = 0.67$; $p < 0.01$). A negative correlation between the basal area and the average number of fertile fronds throughout the studied period was also verified ($r^2 = -0.43$; $p < 0.01$).

The first three axes of the Principal Components Analysis explained 76.8% of the variation in the data. The first axis (45.7%) showed a correlation between the *R. adiantiformis* population structure and the forest succession stage (Fig. 1). The correlations of the descriptors YOU (number of young fronds), ADU (number of adult fronds) and TOT (number of total fronds) with the main component axis one were high and positive (Table 2). On the other hand, the descriptor BA (basal area) was high and the correlation with axis one, negative. Consequently, the number of young, adult and total fronds is higher in environments of lower basal area of tree and shrub species, and vice-versa.

The second and third axes explained 19.4% and 11.7% of variance, respectively, but the only descriptors with values equal to or higher than 0.70 were DBH (Diameter at Breast Height) and TRE (No. of trees) in axis two. Thus, no associations between demographic descriptors and phytossociological parameters shown in axis two and three were above the value considered for interpretation (0.70).

Harvesting potential and monitoring indicators of R. adiantiformis *populations.*—The patterns of population one and two were similar in terms of number and proportion of each development phase during the year (Fig. 2). The number of adult fronds dropped with the first collection, but in the following evaluations the values were similar to those prior to frond harvesting. Likewise, in population three, the recovery in frond number and proportion after harvesting was fast. Bud production was intensive in August 2005, in all sampled populations (including the non-harvested area).

In general, frond regeneration after the cuts was rather fast in the managed populations, evidenced by the adult frond numbers found after the collections (Fig. 2). It was also noticed that the demographic dynamism of natural *R. adiantiformis* populations is considerable, as evidenced by the variations in frond number and proportion over the study year in different development phases of the non-managed population (population four) (Fig. 2). However, between August 2004 and August 2005, the relative frequency of adult fronds decreased in this population.

No significant differences were observed among the traditional management systems (populations one, two and three) in relation to the proportion of frond categories (Table 3). However, populations one and two revealed differences as compared to population four (non-managed), due to distinct proportions of adult and dead fronds. In population two, the number of adult fronds was higher than in the non-managed population (population four). Concerning the number of dead fronds, values were higher in population four (non-managed), differing from populations one and two. The proportion of fertile fronds was lower in population one when compared to population four. The other comparisons for this trait indicated no differences.

Discussion

Environmental aspects.—The high variation found in the initial frond development phases has been reported in other studies on this species (Milton, 1987; Geldenhuys and Van der Merwe, 1994; Conte *et al.*, 2000), and may reflect the remarkable seasonality of bud emersion in the species. According to Geldenhuys and Van der Merwe (1988), bud production begins between May and July in South Africa and reaches a peak between September and November. In the South of Brazil, the most intensive period of bud production is in August and September (Anama, 2002; Baldauf, 2006). Intensive bud production in these months was also confirmed in the first year of this study. This occurred in both harvested and non-harvested areas suggesting that this emergence is not related to the management regime employed (Fig. 2).

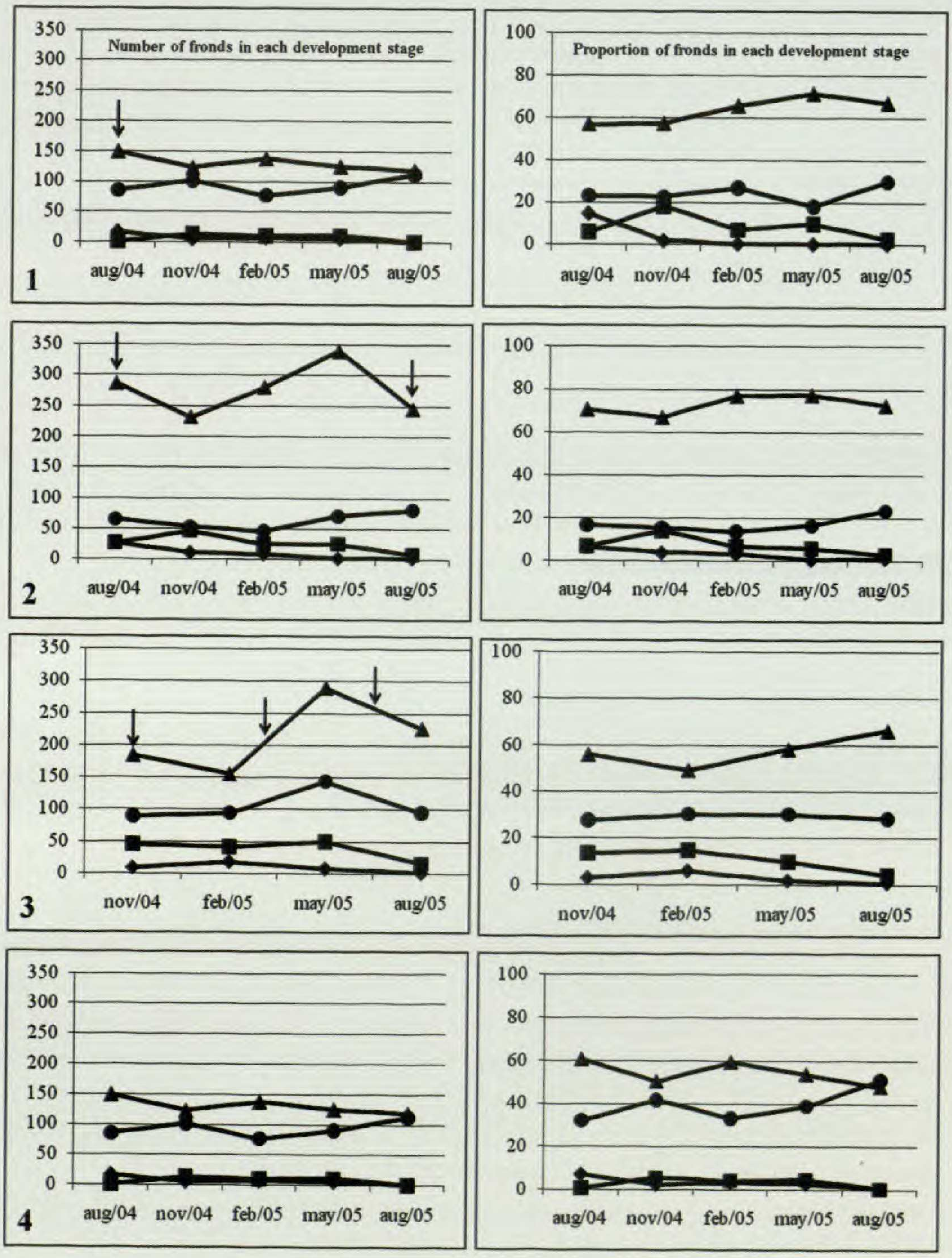

FIG. 2. Number (left) and proportion (right) of fronds in each development stage in four populations of leatherleaf fern (*Rumohra adiantiformis* (G. Forst.) Ching) in Brazilian Atlantic Rainforest. The numbers in each figure represent the population number (according to text and Table 1). Buds are represented as diamonds, young fronds as squares, adult fronds as triangles, and dead fronds as circles. The arrows on adult fronds indicate the period of harvesting.

Climatic factors can alter the period and intensity of frond production. Results of previous studies indicated rainfall as one of the factors that influence bud emergence in the species most strongly. In South Africa, Milton and Moll (1988) concluded that frond number and size in the control plots of

TABLE 3. Values of Kolmogorov-Smirnov test (D_{max}) with Bonferroni correction (α_B) (above the diagonal) and p-values (below the diagonal) for proportions of fronds in each development stage. Values followed by an asterisk differ significantly considering α_B. The last column shows Kruskal-Wallis test for the proportion of fertile fronds. Values followed by the same letter do not differ from each other according to the Dunn test (column comparison).

Population	1	2	3	4	Fertile Fr.
1	X	0.07	0.05	0.16*	1.6a
2	>0.05	X	0.12	0.23*	4.1ab
3	>0.05	<0.05	X	0.12	4.8ab
4 (control)	<0.01	<0.01	<0.05	X	19.3ab

their experiments were positively associated with rainfall in the months prior to evaluation. Conte *et al.* (2000) also stated that in the spring of 1999 the production of new fronds in the Southwest of Brazil decreased remarkably, due to low soil moisture, when rainfall was less than half of the long-term averages for the same period in previous years. Ticktin *et al.* (2007) noted that changes in frond density and rates of frond production over time coincide closely with changes in precipitation levels over time and that seasonal rainfall rates were significantly correlated with rates of frond production in two Hawaiian fern species. Thus, the lower number and proportion of buds found in the evaluation carried out in August 2005 (when compared with 2004) are probably due to the average rainfall value of the previous three months, which was approximately half the value measured in 2004.

In relation to the vegetative propagation of the species, water availability in the months prior to bud formation possibly results in water reserves for the plant, which reduces the chances of bud desiccation after emergence. On the other hand, Stamps *et al.* (1994) claimed that the emergence of new fronds is associated with soil temperature, which increases during the sunny periods; this explains the inverse and significant correlation between monthly precipitation and frond production observed here.

Our results further show a probable reduction in *R. adiantiformis* populations caused by forest regeneration, as shown in the principal component analysis. This analysis showed that when the basal area of a particular location increases, the number of young and adult fronds tends to decrease. This tendency was also confirmed by Milton and Moll (1988), who observed that the density of *R. adiantiformis* populations in South Africa was negatively correlated with tree height and canopy cover. Local harvesters mentioned this aspect as a critical limit for leatherfern harvesting in the Atlantic Rainforest (Baldauf *et al.*, 2008). Additionally, the lower number of fertile fronds registered for population one is probably related to the higher basal area of the plots where this population occurs. The results presented here show that fertile fronds are more common in areas with more solar radiation. This fact emphasizes the need for open canopy areas to maintain viable *R. adiantiformis* populations.

Harvesting potential and monitoring indicators for R. adiantiformis.—One of the most remarkable tendencies of *R. adiantiformis*, and highly relevant for species management, is the rapid frond regeneration after harvesting. In general, frond regrowth of populations is fast, as evidenced by the number and proportion of adult fronds in the evaluation carried out after the collection. The results for population three are particularly noteworthy, since they represent the most commonly used harvesting frequency in the region under study (Baldauf *et al.*, 2007).

The results obtained here differ largely from those of populations studied in South Africa, where *R. adiantiformis* plants seem unable to maintain frond density and size when harvested (Milton, 1987; Milton and Moll, 1988; Geldenhuys and Van der Merwe, 1988). According to Milton (1991), a period of five years is insufficient for *R. adiantiformis*, under natural conditions in the indigenous forests of the southern Cape, to recover from total or partial defoliation. In these forests, only 50% of all pickable fronds per plant may be harvested and the harvesting cycle was extended to 15 months to give plants sufficient time to recover (Geldenhuys and Van der Merwe, 1994). These contrasting results may be related to climatic differences between the areas. According to Stamps *et al.* (1994), *R. adiantiformis* grows faster under a high-temperature regime than under a low-temperature regime. In another study (Strandberg, 2003), it was observed that the production of new fronds and the time required for leaves to mature were also strongly associated with degree days, daylight hours, solar radiation, and soil temperature. However, there are no remarkable differences in the temperature regime of the areas in question. Thus, other factors might be involved.

One possibility, already mentioned, is the influence of rainfall on the production of fronds. Annual rainfall in the Maquiné area varies from 1400 mm to 1800 mm (Hasenack and Ferraro, 1989), whereas the annual rainfall in the South African area ranges from 920 mm to 1250 mm (Milton and Moll, 1988). Since the emergence of new fronds shows a positive correlation with rainfall, this could be an explanation for the differences found.

Milton (1991) attributes the slow recovery in South African populations in part to long leaf longevity in this species. In Brazilian natural populations, fronds are also very long-lived (Anama, 2002; Conte *et al.* 2000), but despite this fact they can recover rapidly. Additionally, the higher harvest rates applied to Brazilian populations as compared with the rates employed in South Africa could cause reductions in frond production, as reported by Milton (1991), but such reductions do not occur in Brazil (at least not when the traditional management system is employed). Geldenhuys and Van der Merwe (1988) point out that frond production in South Africa appears to be nutrient limited, and frond removal also reduces nutrient availability. Therefore, another possibility is that, in Brazilian populations, there would be no nutrient limitation to the species growth. Nevertheless, further studies are necessary to confirm the influences of edaphoclimatic conditions on the population structure of *R. adiantiformis*.

Conte *et al.* (2000) suggested that a cutting cycle of five events each year (cycles of two months during the rainy season and of three months in the dry season) could maintain the sustainability of *R. adiantiformis* populations in the State of São Paulo, in the southeast region of Brazil. However, in an experimental study conducted in Rio Grande do Sul, in the south of Brazil, Anama (2002) applied different harvesting frequencies and concluded that traditional harvesting, which consists of a maximum of three annual cuts, was the only treatment that would not affect frond number and size.

Differences in ideal harvesting frequencies between the South and Southeast regions of Brazil reinforce the influence of rainfall on frond production, since the annual rainfall in the area where Conte *et al.* (2000) conducted their study is 2300 mm (CEPAGRI, 2010), higher than the values observed in other areas where the species is harvested in Brazil. These differences in appropriate harvesting regimes also show that monitoring indicators must be determined on a regional scale.

The results reported here agree with those obtained in the study by Anama (2002), since they reinforce the absence of negative impacts of traditional harvesting on the species population structure. The differences in dead frond proportions found among populations one and two and population four (control) probably reflect the fact that the harvesters are removing adult fronds from populations one and two. Thus, less dead fronds would be expected in these populations than in the control, where fronds die naturally or remain on the plant for a long time. Nevertheless, no differences were observed on the proportions of buds and young fronds among the populations under investigation, which may be considered a sign of harvesting sustainability. According to Peters (1996), the first sign of over-exploration of a plant population is expressed in its size class distribution. In most species, the most visible effect of over-exploration is a reduction in the number of seedlings and young plants. Since *R. adiantiformis* is a rhizomatous species, the initial frond development phases (buds and young fronds) are understood as equivalent to seedlings and young plants of tree species in order to monitor the harvesting activity.

In view of the fact that in managed populations the variation in the proportion of young fronds is lower than of buds, the former was considered a better indicator of the demographic dynamism, characteristic of the species and of possible impacts of frond harvesting. The reference values for this indicator are variable, due to a period of intensive frond formation at the end of the winter (August and September). Based on the fact that there is no difference in the proportion of young fronds in the managed populations when compared with the non-managed population, references values were established for monitoring. These values comprise the range of proportions obtained in all studied populations plus a safety margin. Therefore, the value of young fronds should be between 10% and 20% in the period between September and December (after bud formation), whereas in other periods of the year a proportion between 5% and 15% would be expected.

The demographic structure of leatherleaf fern is largely influenced by climatic factors and forest succession and must therefore be continuously monitored over several years. It is also important to consider that the results and monitoring indicators presented here are based on studies carried out at few sites and should be revised periodically. In cases that require a more in-depth analysis, it is possible to analyze the genetic diversity of the managed populations, based on allozyme markers. By this technique, the main genetic diversity indexes can be determined; in case of population overexploitation, these values may be reduced (Baldauf *et al.*, 2008). Once the demographic data are relatively easy to obtain, evaluations may include the local harvesters of the collection areas, helping to evaluate the populations in a participatory monitoring process.

Finally, it should be emphasized that the low ecological impact of the traditional management systems is not sufficient for the maintenance of a leatherleaf fern population, since it is a pioneer species that tends to disappear during forest succession. Hill and Silander Jr. (2001) studied the pteridophyte species *Dennstaedtia punctilobula* (Michx.) T. Moore and understood that any event that maintains or results in canopy openness (tree death caused by disease, windthrow or forest harvesting, or the elimination of a shrub layer by browsing) favors the persistence of *D. punctilobula*. Analogously, the maintenance of *R. adiantiformis* populations also depends on further management measures that would improve productivity, as for example the management of "capoeira" (naturally regenerated second-growth forest) areas. This, along with the farming of perennial agricultural species, could be a way to guarantee income and food security to the harvesting families.

Acknowledgements

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